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REFERENCE: **Intermountain Power Project -- Unit #2**
Analysis of Used Filter Bags -- Prior to Sonic Horn Operation
Purchase Order No. 12054

BACKGROUND

Intermountain Power Service Corp. (IPSC) operates two GEESI reverse-gas fabric filters serving two identical 840 MW coal-fired boilers, Unit #1 and Unit #2. Each fabric filter consists of three separate casings with sixteen compartments per casing, each containing 396 filter bags, for a total of 19,008 bags per unit. The bags are 12.0" diameter by 32' 11-11/16" long (under 75 lbs. tension) with cap top, compression band bottom, and eight anti-collapse rings. They are fabricated from 13.5 oz/yd^2 glass fabric (warp face out) with Burlington Glass Fabrics' (now BGF Industries') I-625 acid-resistant finish.

It has been well-documented that different versions of I-625 finish were utilized for each of the two units, due to a change made by BGF in the interim. Unit #1 bag fabric was finished with the original I-625 finish which is light gray in color and yields a more supple fabric hand. Unit #2 bag fabric was finished with a revised I-625 finish which is darker brownish-gray in color and yields a somewhat stiffer fabric hand. These finishes are referred to hereinafter as "light" (Unit #1) and "dark" (Unit #2).

Startup (initial flue gas) and commercial operation dates for the two baghouses were as follows:

Unit #	Startup Date	Commercial Operation
1	3/28/86	June 1986
2	2/16/87	May - June 1987

Both units are currently being retrofitted with sonic horns for the purpose of reducing the operating ΔP.

REQUEST and SAMPLE DESCRIPTION

A total of nine (9) bags, removed from Unit #2 in November 1993, were submitted for analysis to determine their condition prior to sonic horn operation. Some ring cover stitching failures had been experienced in the months prior to the removal of these bags, and initial instructions from Mr. Jeff Payne of IPSC were to ignore these failures when analyzing the bags. Subsequently, IPSC grew increasingly concerned about the ring cover failures and decided that they did want them analyzed, per instructions from Ms. B.A.S. Stephens on January 19, 1994.

The bags were received on December 1, 1993, and were marked on their shipping cartons and on the bag caps for identification, as follows:

Casing/Compartment No.	Bag/Thimble No.	Removal Date
A3	J-5	11/5/93
A9	O-16	11/5/93
A15	C-10	11/6/93
B8	P-5	11/13/93
B10	I-14	11/6/93
B15	D-4	11/6/93
C8	P-8	11/6/93
C11	I-11	11/6/93
C14	O-22	11/6/93

Since only one bag was removed from any one compartment, the bags are referred to by their compartment number in this report.

Assuming that these were original equipment bags, they had been "in service" for about 80 months.

SUMMARY and CONCLUSIONS

Except for the ring cover stitching failures, both existing and impending, the bags were in excellent physical condition. Fabric strength had declined only modestly compared to that of used IPP Unit #2 bags tested by GFTS in 1990 and 1991 after 36 months and 48-53 months of service respectively. In fact, the Mullen burst strength and MIT flex values for all bags (except for the warp MIT on one bag) still exceeded the minimum specified values for new fabric, even after eighty months of service. In addition, there was no evidence of any localized fabric wear or degradation that could cause premature bag failure.

The average weight of these bags (33.5 lb) was lower than that of the Unit #2 bags tested in 1990 and 1991; however, these weights may reflect differences in boiler, baghouse, or compartment operations that existed just prior to bag removal, or differences in the bag removal procedures, rather than any permanent change in the mass of the residual ash cake. In-situ bag weighing, performed at the same time during the filtration/cleaning cycle, is a preferable method of comparing bag weights.

In spite of the lower bag weight, the "as-received" fabric permeability, averaging 1.11 cfm, was substantially lower than that of the Unit #2 bags tested in 1990 and 1991, which averaged 1.40 cfm in both cases. Vacuumed permeability of the current bags was in the same range (around 20 cfm) as that observed on previous used bags, indicating that there had been no significant increase in ash impregnation of the fabric during the past 2-3 years of operation.

One of the bags submitted; Compartment A3, Bag J-5; was made of fabric with the "light" finish, as originally used for Unit #1. It is unknown whether this bag was installed in Unit #2 as original equipment or as a subsequent replacement bag. However, the fabric from this bag differed substantially from the standard "dark" finished fabric in Unit #2 in the following respects: higher permeability (both as-received and vacuumed), higher warp MIT, lower fill MIT and Mullen burst, and lower bag weight. All data from this "light" bag were excluded from the average data presented in this report.

A summary of the data obtained on the Unit #2 ("dark" finished) bags tested at various service intervals is presented in Table 1 and compared to the new fabric specifications and QC data.

It seems quite likely that the ring cover stitching failures, that are either already present or impending, will be the limiting factor in determining the ultimate life of the bags. It is possible that the ring cover failures, if they become as extensive as it appears they will, may negate any life extension (of the current set of bags) that may have been achieved due to ΔP reduction resulting from the sonic horns. Additionally, it will be interesting to evaluate the effect (if any) of sonic horn operation on the frequency of ring cover failures. A detailed discussion of the ring cover failure analysis is presented below.

RING COVER STITCHING FAILURE ANALYSIS

All of the bags had eight expansion rings, each of which had a double layer self-material ring cover that was attached with two rows of double needle type 401 multithread chain stitching using type B-4 (150 1/4) Teflon-coated fiberglass sewing thread.

The upper two rings and cover assemblies were taken from every bag, as were any others that exhibited visible damage during the initial external examination of the bags. It is entirely possible (perhaps even likely) that we did not find all of the ring covers that had some damage present. For the sake of brevity, all rings and covers will be described as their position numbered from the top.

The selected ring and cover assemblies were vacuumed prior to detailed examination. On the inside, at the start & stop point of the attachment stitching, there was a cluster of 2" to 3" long thread tails (typical for chain-stitched ring covers). There were no dust accumulations "growing" at the tips of the loose threads, so there was no "ball and chain" effect (a nodule at the end of a loose yarn or thread can whip around in the gas flow and cause abrasion where it repeatedly strikes the bag's surface). These thread tails were also too strong to be broken by hand; i.e., the thread does not appear to have suffered any significant degradation.

TABLE 1

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAG/FABRIC PROPERTIES vs. LENGTH OF SERVICE
"DARK" (I-625G) FINISHED FABRIC ONLY

FABRIC/BAG PROPERTY	NEW FABRIC (a)		USED BAG FABRIC		
	SPECIFICATION	QC DATA			
Bag Removal Date Length of Service	Not Applicable " "	Not Applicable " "	1990 (b) 36 mo	1991 (c) 48-53 mo	1993 80 mo
Bag Weight (lb)	" "	" "	36	43	33.5
Permeability (cfm/ft^2): As Received - Vacuumed -	 " " " "	 " " " "	 1.40 20.7	 1.40 19.9	 1.11 22.8
Fabric pH	" "	" "	11.24	11.43	10.72
Mullen Burst (psi (d))	550 min.	829	793	702	694
MIT Flex (cycles): Warp - Fill -	 8,000 min. 2,000 min.	 38,500 10,300	 10,800 3,990	 12,800 3,780	 11,200 3,160
Fabric Properties (Washed): Weight (oz/yd^2) - Permeability (cfm/ft^2) - Loss on Ignition (%) -	 13.5 $\pm$ 5% 35 - 55 4.0 min.	 Not Reported 45.7 5.1	 13.70 52.8 4.70	 13.67 55.0 4.93	 13.59 64.7 4.74

(a) "The Design, Start-Up and Operation of the Intermountain Power Project, Unit #2 Fabric Filter System"; R.L. Miller, et. al; Seventh Symposium on the Transfer and Utilization of Particulate Control Technology; Nashville, TN; 1988. (QC data are averages of the "low" and "high" values that were reported.)

(b) Laboratory Report No. 683; GFTS, Inc.; May 25, 1990. (Averages include one "dark" replacement bag operating in Unit #1, except for Mullen burst and MIT flex.)

(c) Laboratory Report No. 955; GFTS, Inc.; December 3, 1991. (Averages include one "dark" replacement bag operating in Unit #1, except for Mullen burst and MIT flex.)

(d) Used bag Mullen burst values are "net" (gross-tare; tare=50 psi). The Mullen burst values for new fabric were not specified whether "net" or "gross".

Each of the ring covers was also slit open for several inches to examine the ring itself and the condition of the internal fabric layer surface. In each case, the ring still had a dull metallic luster and was still smooth (i.e., they were not rusty or corroded), and consequently, the internal fabric was not visibly worn. None of the ring covers exhibited any external wear (as if from bag to bag abrasion).

The box in which bag B8 was received was labeled in handwriting "2 Bag Rings", and at the second and third rings, it was immediately evident on initial examination that the respective ring covers had indeed failed. On closer examination, we saw a beginning failure at the fifth ring cover.

The covers of the second and third rings on B8 were becoming detached from the bag proper for about half the circumference due to failure of the sewing thread of the ring cover attachment stitching. Due to the massive nature of the failure, the initial cause was not clear, although there were some thread breaks in the relatively intact stitching of the remaining circumference. These occurred on the inside at points where the stitching intersected longitudinal fold lines which result from the collapse of the bag during reverse-gas cleaning. The bag proper in each case had not yet suffered any failures or significant wear due to the failed ring cover.

The second ring on A15 and the first ring on B15 exhibited similarly failed ring covers (they were becoming detached for half the circumference on A15 and one-third the circumference on B15). Like B8, there were also a few broken stitches at reverse-gas fold lines in the otherwise intact remainder of the circumference, and there was no damage to the bag proper. It seems likely that the massive ring cover failures on these two bags, as well as B8, started as small thread breaks, then "grew" (via "unzipping" of the chain stitching?).

After vacuuming, it was also noted that the fifth ring covers, which were just beginning to fail, on both bags B8 and B15 had broken stitches, six breaks on B8 and two on B15. In each case, they occurred at the internal thread loops at the point of intersection with reverse-gas fold lines.

The remaining ring covers from the other bags were then vacuumed and examined. The following list summarizes, for all the rings selected, the number of broken stitches found at each one (or if it was a massive stitching failure):

Bag	Ring (no. of broken stitches)
A3	first (none), second (1)
A9	first (none), second (1)
A15	first (3), second (massive)
B8	first (1), second (massive), third (massive), fifth (6)
B10	first (none), second (none)
B15	first (massive), second (2), fifth (2)
C8	first (1), second (none)
C11	first (none), second (2)
C14	first (none), second (none)

The first ring cover of B8 was unusual in that there were broken stitches on the outside that were not associated with reverse-gas fold lines -- it was probably scuffed or scraped on handling.

All of the other stitch breaks occurred at the points where they intersected reverse-gas fold lines. This type of failure is evidently due to the combination of the following factors (not listed in any special order):

- The use of chain stitching rather than the more usual lock stitching to attach the ring covers. When "pinched" during reverse-gas cleaning, the internal loops of thread from the chain stitching slide across one another which can lead to abrasion (lock stitching does not form a looped structure).

- The use of type B-4 fiberglass thread (150 1/4) rather than the heavier type B-6 (150 2/3) more commonly used for the ring covers of large fiberglass filter bags. The thread did not suffer from general deterioration, but was not heavy enough to resist wear at the points of abrasion.

- Long service -- these bags are more than six years old.

TEST DATA and OBSERVATIONS

Physical Condition of the Bags: All of the bags were in excellent physical condition with no signs of service-related wear (except for the ring cover failures that were discussed in the previous section). The reverse-gas collapse folds were moderate to light in intensity, and no "ancillary lines" were present at the collapse folds in the top sections of the bags (as are sometimes observed on bags cleaned with sonic horns). No "accordion-type" creases were evident in the bottom sections, indicating that adequate bag tension had been maintained.

In general, the bags had a moderate-to-heavy residual cake of tan/gray colored ash inside, with no crust or nodulation. This cake was readily removed by vacuuming. The bag exteriors were somewhat dusty, but this could have resulted from contamination during removal, handling, and shipping.

Fabric Strength: Both the Mullen burst and MIT flex values were remarkably high for glass bags that have been in service for 80 months. This is undoubtedly due in part to the low baghouse operating temperature, 275°F outlet, and to the alkaline fly ash (used fabric pH = 10.7) which have moderated the effects of acidic flue gas on the acid-resistant finished glass fabric.

The average Mullen burst strength was essentially the same after 80 months' service (694 psi, net) as after 50 months' service (702 psi, net), and the average MIT flex had decreased by only 12-16% during this period. Refer to Tables 1 and 2 for comparison of the average strength of the current bags to that of new fabric and of previously tested used bags. Data on individual bags is presented in Table 3 for Mullen burst (top, middle, and bottom sections) and in Table 4 for MIT flex.

Note that the "light" finished fabric (Bag A3) had lower Mullen burst and fill MIT values and higher warp MIT values than the "dark" finished fabric that is the standard in Unit #2. These results generally correspond to previous comparisons of the two different finished fabrics at IPP.

Permeability and Bag Weight: Average permeability data is compared to that of previously tested used bags in Table 1. The as-received permeability was about 20% lower (1.11 cfm vs. 1.40 cfm) than it had been on the used bags previously tested, in spite of a lower average bag weight. Since the bags are subjected to much greater movement during removal, shipment, and sample preparation than they are during normal in-service cleaning, the actual in situ fabric permeability is always considerably less than that measured in the laboratory. As-received bag weights may also be less than the actual in situ bags weights for the same reason, depending on the bag removal procedure.

Vacuumed permeability values were in the 20-25 cfm range, about the same as that of used bags from Unit #2 that were previously tested. This vacuumed permeability range is indicative of "normal", minimal penetration of ash into the fabric structure.

Note that the "light" finished fabric (Bag A3) had a considerably lower bag weight and higher permeability, both as-received and vacuumed, than the "dark" finished fabric that is the standard in Unit #2. These results generally correspond to previous comparisons of the two different finished fabrics at IPP.

The permeability profiles (top, middle, and bottom) of each bag are presented in Table 5 (As Received) and Table 6 (Vacuumed). Individual bag weights (along with bag lengths and fabric pH values) are presented in Table 7.

__Fabric Construction and Properties__: A washed sample of fabric from the middle of each bag was analyzed for construction, L.O.I., and permeability. This data is summarized and compared to original QC data and to the specification in Table 2, and presented for each individual bag in Table 8. All bag fabrics met the count and weight specifications. All fabric L.O.I. values were within the range reported for new fabric of the same finish type. Average permeability values were approximately 40% higher than the range reported for new fabric, but this is not abnormal considering the handling that the fabric experiences during bag fabrication, packing, installation, in-service use, removal, and washing (though performed carefully).

__Raw Data__: All raw data (permeability, Mullen, and MIT) is on file at GFTS, and it is available upon request.

TABLE 2

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAGS REMOVED NOVEMBER 1993
AVERAGE FABRIC PROPERTIES vs. NEW FABRIC QC DATA
(Testing performed on washed samples, except Mullen and MIT on vacuumed samples)

"DARK" FINISH (I-625 G)

FABRIC PROPERTY	SPECIFICATION	QC DATA MIN	QC DATA MAX	USED BAG DATA AVG	USED BAG DATA MIN	USED BAG DATA MAX	% CHANGE*
Loss On Ignition: (%)	4.0 min	4.6	5.6	4.74	4.19	5.36	- 7%
Permeability: (cfm/ft^2)	35-55	41.8	49.6	64.7	61.4	67.7	+ 42%
Mullen Burst: (psi**)	550 min	757	901	694	628	739	- 16%
MIT Flex (cycles):							
Warp -	8,000 min	36,000	41,000	11,200	7,770	17,500	- 71%
Fill -	2,000 min	9,639	10,905	3,160	2,560	3,470	- 69%
Weight: (oz/yd^2)	13.5 ± 5%	Not Reported		13.59	13.39	14.03	N/A
Count (per inch):							
Warp -	44 ± 2	Not Reported		43	43	43	N/A
Fill -	24 ± 2	Not Reported		24	24	24	N/A

All used bag fabric samples had a 3x1 Twill (left hand) weave, ECDE 37 1/0 warp yarns, and ECDE 75 1/3 (2 texturized and 1 filament) fill yarns, as specified.

* % Change compared to the average of the minimum and maximum QC values. Mean QC data were not reported.

** Used bag Mullen Burst values are "net" (gross-tare; where tare = 50 psi). The specification and QC Mullen Burst values were not specified whether "net" or "gross".

TABLE 3

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAGS REMOVED NOVEMBER 1993
MULLEN BURST PROFILE (psi, net)

COMPARTMENT	BAG SECTION			AVERAGE
	TOP	MIDDLE	BOTTOM	
A3*	658	582	538	593
A9	685	710	707	701
A15	733	703	662	699
B8	633	617	635	628
B10	662	708	677	682
B15	725	745	687	719
C8	620	670	665	652
C11	778	713	727	739
C14	723	720	748	730
AVERAGE*	695	698	688	694

* "Light" finished fabric -- data excluded from averages.

The value for each bag section is an average of 3 tests. Testing was performed on vacuumed samples.

TABLE 4

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAGS REMOVED NOVEMBER 1993
MIT FLEX DATA (cycles to failure)

COMPARTMENT	WARP	FILL
A3*	15,100	2,010
A9	13,500	3,470
A15	10,100	3,320
B8	12,200	2,760
B10	9,110	2,560
B15	11,100	3,240
C8	7,770	3,090
C11	17,500	3,400
C14	8,600	3,410
AVERAGE*	11,200	3,160

* "Light" finished fabric -- data excluded from averages.

Each warp MIT value is an average of 3 specimens tested, and each fill is an average of 6 specimens tested. Testing was performed on vacuumed middle sections using an 0.03" head, 4 lb weight, and #8 spring. Values were corrected to 55% RH, using the attached formula, and rounded to three significant figures.

TABLE 5

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAGS REMOVED NOVEMBER 1993
"AS RECEIVED" PERMEABILITY PROFILE (cfm/ft^2 @ 0.5 WG)

COMPARTMENT	BAG SECTION			BAG AVERAGE
	TOP	MIDDLE	BOTTOM	
A3*	1.28	1.43	1.99	1.57
A9	1.01	0.98	1.16	1.05
A15	1.21	0.92	1.14	1.09
B8	1.26	1.18	1.39	1.28
B10	0.85	0.85	1.03	0.91
B15	1.07	0.98	1.33	1.13
C8	1.07	1.03	1.50	1.20
C11	1.04	0.80	1.18	1.01
C14	1.16	1.07	1.52	1.25
AVERAGE*	1.08	0.98	1.28	1.11

* "Light" finished fabric -- data excluded from averages.

The value for each bag section is an average of 3 tests.

TABLE 6

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAGS REMOVED NOVEMBER 1993
VACUUMED PERMEABILITY PROFILE (cfm/ft^2 @ 0.5" WG)

COMPARTMENT	BAG SECTION			BAG AVERAGE
	TOP	MIDDLE	BOTTOM	
A3*	28.1	33.6	33.7	31.8
A9	20.3	24.8	19.5	21.5
A15	23.9	21.7	21.5	22.4
B8	20.4	21.2	21.1	20.9
B10	22.1	25.5	25.9	24.5
B15	24.0	24.6	29.4	26.0
C8	20.1	21.4	27.7	23.1
C11	23.3	27.9	22.5	24.6
C14	20.1	17.2	19.9	19.1
AVERAGE*	21.8	23.0	23.4	22.8

* "Light" finished fabric -- data excluded from averages.

The value for each bag section is an average of 3 tests.

TABLE 7

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAGS REMOVED NOVEMBER 1993
MISCELLANEOUS TEST DATA

COMPARTMENT	BAG WEIGHT (lb) "AS RECEIVED"	BAG LENGTH*	FABRIC pH **
A3***	24	32' 9"	10.57
A9	31	32' 11"	10.62
A15	30.5	32' 10"	10.72
B8	33.5	32' 11"	11.27
B10	40.5	32' 11"	10.48
B15	33.5	32' 11-1/2"	10.73
C8	32	32' 10"	10.84
C11	30.5	32' 11"	10.66
C14	35.5	32' 10"	10.44
AVERAGE***	33.5	32' 10-1/2"	10.72

* Measured at the seam under firm hand tension

** 5 g as-received fabric per 100 ml distilled water

*** "Light" finished fabric -- data excluded from averages.

TABLE 8

INTERMOUNTAIN POWER UNIT #2 - PRIOR TO SONIC HORN OPERATION
USED BAGS REMOVED NOVEMBER 1993
FABRIC PROPERTIES - WASHED SAMPLES

COMPARTMENT	WEIGHT (oz/yd^2)	PERMEABILITY (cfm/ft^2)	L.O.I. (%)
A3*	13.59	58.2	5.35
A9	13.64	62.7	5.34
A15	13.44	62.8	4.29
B8	13.39	64.4	4.44
B10	13.57	64.0	4.19
B15	14.03	67.3	5.36
C8	13.50	67.1	4.24
C11	13.55	67.7	5.31
C14	13.57	61.4	4.77
AVERAGE*	13.59	64.7	4.74

All samples had the same weave, count, and nominal yarns sizes, as follows:

Weave:	3x1 Left-Hand Twill
Count (Warp x Fill):	43x24 per inch
Warp Yarns:	ECDE 37 1/0
Fill Yarns:	ECDE 75 1/3 (2 texturized + 1 filament)

* "Light" finished fabric -- data excluded from averages.

MIT FLEX CORRECTION FORMULA

MIT Flex values are highly dependent on relative humidity. Actual raw data are corrected to a standard 55% relative humidity using the following empirical formula:

$$\ln F_{55} = \ln F_H + (0.35 \times (H - 55))$$

Where: F_{55} = MIT Flex corrected to 55% R.H.

F_H = Raw Flex value obtained at H% R.H.

H = Humidity at which test performed